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A Periodic Switching Diversity Technique for a Digital FM Land Mobile Radio

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***Abstract*—A simple and efficient diversity technique is proposed for use in a digital FM land mobile radio communication system. This technique receives two RF signals periodically by switching two antenna branches at a rate moderately higher than the bit rate. The improved bit error rate (BER) performance resulting from the use of diversity is shown to be the effect of transforming the probability density function of the signal energy per bit to noise power density ratio to a sharper distribution. Laboratory simulation test results show that in a Manchester-coded frequency-shift keying (FSK) system with a bit rate of 600 bit/s and a frequency deviation of ±5 kHz, the diversity gain at an average BER of 1×10^{-3} is about 10 dB for an optimum switching rate of about 2 kHz. This diversity improvement is also verified by the field test performed in a suburban area.**

I. INTRODUCTION

IN LAND MOBILE radio communication systems, signal transmission between a base station and a mobile unit is usually performed not only by a direct line-of-sight route, but also via multiple random paths because of reflection, scattering, and diffraction. Thus in the case of UHF or microwave land mobile radio, rapid and deep fading phenomenon will occur on the received signals at both stations as the mobile unit moves through an interference field made of many waves which arrive with different amplitudes and phases. This fading phenomenon is generally called multipath fading or Rayleigh fading. A received signal suffering such fading phenomenon has a Rayleigh distributed envelope and a uniformly distributed phase [1]-[3].

In a Rayleigh fading environment, signal transmission performance is greatly degraded. Diversity reception is one of the most useful techniques to reduce the influence of such fading on signal transmission performance [4], [5]. Many diversity techniques for land mobile radio have been proposed and researched. Most of them adopt a method which combines the RF signals on the different diversity branches suffering uncorrelated Rayleigh fadings. Typical combining methods are selection, maximal ratio, and equal gain [6], [7]. Switching diversity using a single receiver is a kind of selection combining diversity technique with an advantage for mobile radio use because of equipment simplification and cost economy [8], [9].

This paper proposes a more simplified switching diversity technique to be used in a digital FM land mobile radio. This technique adopts a simple method which receives two RF signals periodically by switching two antenna branches at a rate moderately higher than the bit rate. In Section II, the background for such a concept is given, and it is shown that the cause of diversity effect on the bit error rate (BER)

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performance is due to transforming the probability density function (pdf) of the signal energy per bit to noise power density ratio to a sharper distribution. Section III analyzes the diversity improvement on the BER performance. In Section IV, the laboratory simulation test results for a Manchester-coded frequency-shift keying (FSK) system with limiter-discriminator detection are described. For the bit rate of 600 bit/s and frequency deviation of ±5 kHz, an optimum switching rate is about 2 kHz. In such a case, the diversity gain at the average BER of 1×10^{-3} is about 10 dB. Section V deals with a field test performed in a suburban area. It is proved that the experimental system demonstrates diversity action in a real fading environment.

II. BACKGROUND

Two of the authors have clarified the effect of mobile speed on the BER performance in a Manchester-coded FSK system with limiter-discriminator detection in the 900 MHz band by the laboratory simulation test [10].

The fading simulator used in the experiment is able to generate Rayleigh fading [11]. The fading rate, i.e., the maximum Doppler frequency f_D $(=v/\lambda)$, corresponding to mobile speed v and carrier wavelength λ, is variable from 0 Hz to 10 kHz. Fig. 1 shows the effect of the fading rate on the BER performance of a Manchester-coded FSK system with a bit rate of f_b = 600 bit/s and a frequency deviation of Δf_d = ±5 kHz. In this measurement, the predetection IF filter's 3-dB bandwidth is B_{if} = 16 kHz and the postdetection baseband filter's 3-dB bandwidth is B_0 = 626 Hz.

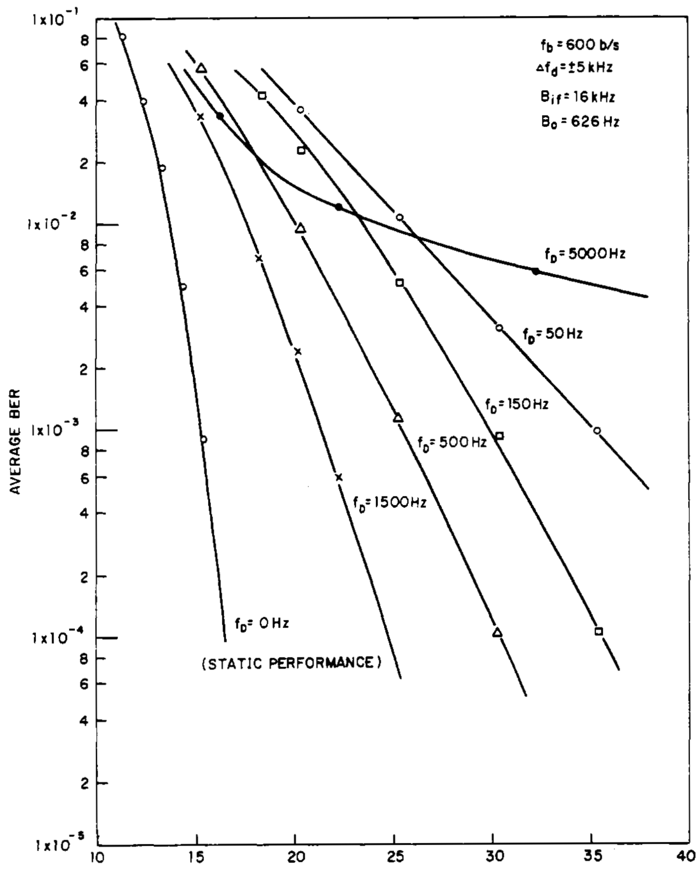


Fig. 1. Effect of fading rate on average BER performance.

From the above laboratory simulation test results, it is found that the average BER performance is closely related to the fading rate, i.e., mobile speed. There exists an optimum value of $f_D \approx 1.5$ kHz in the fading rate corresponding to a fictitious speed of $v \approx 1250$ km/h. The optimum value is not closely dependent on the average signal level.

It is well known that total error probability P_e of an FSK system with limiter-discriminator detection in a Rayleigh fading environment is given by [12]

$$P_e = P_1 + P_2 + P_3 \tag{1}$$

where P_1 is average BER due to Rayleigh envelope fading, P_2 is average BER due to random FM noise, and P_3 is average BER due to time delay spread.

In the above case, average BER P_3 due to time delay spread is negligible because the bit rate of f_b = 600 bit/s is negligibly small in comparison with the coherent bandwidth of B = 250 kHz.[1]

In an FSK system with limiter-discriminator detection, the average BER P_2 due to random FM noise is given by [12]

$$P_2 = \frac{1}{2}\left[1 - \sqrt{2}\left(\frac{\Delta f_d}{f_D}\right)\left\{1 + 2\left(\frac{\Delta f_d}{f_D}\right)^2\right\}^{-1/2}\right]. \tag{2}$$

This result indicates that P_2 is smaller than 5×10^{-3} unless $(\Delta f_d/f_D)$ becomes smaller than 5.0. However, the measured BER P_2 is much smaller than 5×10^{-5} because of the low-pass filtering effect.

The average BER P_1 due to Rayleigh envelope fading is obtained by averaging the static BER performance over the fading dynamic range. The static BER performance can be approximately represented as the following relation [12]:

$$P_e(\gamma) \approx \tfrac{1}{2} e^{-\alpha\gamma}, \tag{3}$$

where γ is signal energy per bit to noise power density ratio and α is a constant parameter determined from the bit rate, frequency deviation, and predetection IF filter bandwidth. Therefore, P_1 is given by

$$P_1 = \int_0^\infty P_e(\gamma)p(\gamma)\,d\gamma \approx \int_0^\infty \tfrac{1}{2} e^{-\alpha\gamma} p(\gamma)\,d\gamma \tag{4}$$

where $p(\gamma)$ is the probability density function (pdf) of γ. As the noise power density N_0 is constant, the pdf of $\gamma = E_b/N_0$ is equal to that of signal energy E_b during one time slot $T = 1/f_b$. Signal energy E_b is given by

$$E_b = \int_0^T e^2(t)\,dt \tag{5}$$

where $e(t)$ is the Rayleigh fading signal. Because $e(t)$ can be

[1] This is a typical value measured by Cox in an urban area such as New York [13].

mathematically represented as a narrow-band Gaussian process [3], the pdf of E_b, i.e., γ, is determined from the Gaussian process autocorrelation function $\psi(\tau)$ [14].

For the quasi-stationary case, where the fading rate f_D is much lower than the bit rate f_b, the averaging time T becomes much shorter than the decorrelation time[2] of $e(t)$. Then, the pdf of γ is approximately given by the well-known exponential distribution

$$p(\gamma)=\frac{1}{\Gamma}e^{-(\gamma/\Gamma)} \tag{6}$$

where Γ is the average signal energy per bit to noise power density ratio. Therefore, P_1 is given by

$$P_1=\frac{1}{2(\alpha\Gamma+1)}\approx\frac{1}{2\alpha\Gamma}. \tag{7}$$

This indicates that P_1 is independent of the fading rate.

However, the above result is not true for the nonquasi-stationary case, where the fading rate is not negligibly small in comparison with the bit rate. For such a nonquasi-stationary case, the pdf of γ is not given by (6), but becomes a sharper distribution with small variance [14]. The shape of its pdf resembles that of Gamma or Erlang's distribution. This result means that the fading dynamic range of γ can be reduced. Therefore, the average BER P_1 due to Rayleigh envelope fading can be reduced by an increase in fading rate. This improvement effect comes from integrating the received signal power over one time slot T, which is not much shorter than the decorrelation time of $e(t)$. Then, the average BER performance can be improved as the fading rate increases.

But, if the fading rate becomes excessively high, the average BER P_2 due to random FM noise, which is given by (2), will dominate. This implies that there exists an optimum value in the fading rate, i.e., mobile speed, for BER performance improvement.

Thus it is concluded that the same improvement effect may be obtained by using a technique that would transform the pdf of γ to a sharper distribution. One of the equivalent techniques is to receive two RF signals periodically by switching two antenna branches at a rate moderately higher than the bit rate. This is a new switching diversity technique in that it does not possess a level detector. A block diagram of the receiver using this periodic switching diversity technique is shown in Fig. 2. The diversity effect on the BER performance is analyzed in the following section.

III. DIVERSITY EFFECT ON BER PERFORMANCE

In the receiver model shown in Fig. 2, let us assume that both of the RF signals received by the respective antennas are multipath fading waves with a Rayleigh distributed envelope

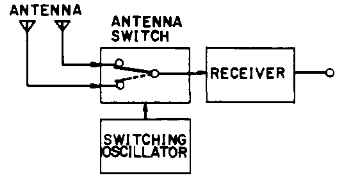


Fig. 2. Block diagram of periodic switching diversity technique.

and a uniformly distributed phase. Furthermore, the two average received signal powers are equal to each other and the fading rate is much lower than the bit rate.

For the quasi-stationary case, where the switching rate is much lower than the bit rate, the receiver input during one time slot is mostly either of the two RF signals received by the respective antennas. Therefore, it is equally probable that the signal energy per bit to noise power density ratio γ becomes either of the γ_1 and γ_2. Considering that the pdf of γ_1 and γ_2 are given by respectively,

$$\begin{cases} p(\gamma_1)=\dfrac{1}{\Gamma}e^{-(\gamma_1/\Gamma)} \\ p(\gamma_2)=\dfrac{1}{\Gamma}e^{-(\gamma_2/\Gamma)}, \end{cases} \tag{8}$$

the pdf of γ is given by

$$p(\gamma)=\tfrac{1}{2}p_1(\gamma)+\tfrac{1}{2}p_2(\gamma)=\frac{1}{\Gamma}e^{-(\gamma/\Gamma)}, \tag{9}$$

where Γ is the average signal energy per bit to noise power density ratio on each diversity branch. This means that the pdf of γ is identical with the pdf of γ_1 and γ_2, corresponding to the nondiversity case. In this case, the average BER P_1 due to Rayleigh envelope fading is also given by equation (7), and the diversity effect is not obtained.

For the nonquasi-stationary case, where the switching rate is much higher than the bit rate, the two RF signals are periodically switched and combined during one time slot. In this case, the signal energy during one time slot becomes one half of the sum of the respective signal energies. Therefore, γ is given by

$$\gamma=\tfrac{1}{2}(\gamma_1+\gamma_2). \tag{10}$$

Considering that the pdf of γ_1 and γ_2 are given by equation (8), respectively, the pdf of γ is given by [4]

$$p(\gamma)=\frac{1}{\Gamma|k|}[e^{-\{2\gamma/\Gamma(1+|k|)\}}-e^{-\{2\gamma/\Gamma(1-|k|)\}}] \tag{11}$$

where k denotes the complex fading correlation between the two fading signals. The above equation corresponds to that of the well-known maximal-ratio combining diversity technique with a signal energy per bit to noise power density ratio of $\Gamma/2$ in each diversity branch. Consequently, the average BER

[2] The decorrelation time is related to the autocorrelation function $\Psi(\tau)$ by the requirement that for any time greater than the decorrelation time, the magnitude of the normalized autocorrelation function must be much less than 1.

P_1 due to Rayleigh envelope fading is given by

$$P_1 = \int_0^\infty P_e(\gamma)p(\gamma)\,d\gamma$$

$$= \frac{1}{2\Gamma|k|}\left[\frac{1}{\alpha + \{2/\Gamma(1+|k|)\}} - \frac{1}{\alpha + \{2/\Gamma(1-|k|)\}}\right]$$

$$\approx \frac{1}{\alpha^2\Gamma^2(1-|k|^2)}. \tag{12}$$

For the intermediate case between the quasi-stationary case and the nonquasi-stationary case, where the switching rate is nearly equal to the bit rate, the average BER P_1 due to Rayleigh envelope fading should be represented as the intermediate form between (7) and (12).

For the nonquasi-stationary case, where the switching rate becomes excessively high, the switching noise should appear at the discriminator output, just as the random FM noise did when the fading rate was increased. Though the random FM noise is a random process, this switching noise is a deterministic process because the switching operation is periodic. Therefore, the switching noise can be removed by a low-pass filter with a lower cutoff frequency than the switching rate.

On the other hand, when one takes the receiver input from one of the antenna branches and gates the received signal on and off periodically at a rate much higher than the bit rate, the signal energy per bit to noise power density ratio γ is given by

$$\gamma = \gamma_1/2. \tag{13}$$

Then, the pdf of γ is given by

$$p(\gamma) = \frac{2}{\Gamma}e^{-(2\gamma/\Gamma)}. \tag{14}$$

In this case, the average BER P_1 due to Rayleigh envelope fading is given by replacing Γ with $\Gamma/2$ in (7). Therefore, the same diversity effect is not obtained.

The feasibility of the periodic switching diversity technique is verified by the following laboratory simulation and field tests.

IV. LABORATORY SIMULATION TEST

A. Simulation Test System

A block diagram of the laboratory simulation test system is shown in Fig. 3.

A pseudonoise (PN) sequence with a bit rate of $f_b = 600$ bit/s and a repetition period of $N = 2^9 - 1 = 511$ bits is used as a test pattern signal. The transmitter consists of an encoder and a 900 MHz band FM modulator. The encoder includes a sum-logic circuit and a code converter. The sum-logic circuit differentially encodes the transmitting test pattern signal to simplify the timing recovery circuit used in the receiver. The code converter transforms a nonreturn to zero (NRZ) type signal into a Manchester-coded type signal to suppress the direct current component. The Manchester-coded signal is fed to the 900 MHz band FM modulator generating a Manchester-coded FSK signal, which is equivalent to an NRZ binary FSK signal with a bit rate of 1200 bit/s. In this case, frequency deviation Δf_d is variable, and the transmitting band is not restricted.

The Manchester-coded FSK signal is transmitted to the receiver through a multipath fading simulator [11] with two branches. The multipath fading simulator provides two fading signals, each having a Rayleigh distributed envelope and a uniformly distributed phase. The fading rate f_D is variable from 0 Hz to 10 kHz. The envelope correlation ρ between the two fading signal envelopes is also variable from 0 to 1.

The receiver consists of an RF switch unit, an FM receiver, and a decoder. The RF switch unit consists of a p-i-n diode switch and an astable multivibrator with adjustable free-running frequency. The FM receiver is a conventional double-conversion type using a limiter-discriminator. Its total noise figure is $N_F = 9.8$ dB. Two Butterworth crystal filters are used as the first and second IF filters of this FM receiver. Overall 3-dB predetection bandwidth is $B_{if} = 16$ kHz. The decoder is composed of a baseband filter, a timing recovery circuit, a decision circuit, and a difference-logic circuit. The baseband filter is a Gaussian type active filter with 3-dB bandwidth of $B_0 = 626$ Hz. The baseband Gaussian filter is used for low-pass filtering of the discriminator output. The timing recovery circuit is composed of a digital phase-locked loop. The recovered timing error is smaller than ±9 degrees. Using recovered timing, the low-pass filtered output is decided upon as "0" or "1" and regenerated by the decision circuit.

After being differentially decoded by the difference-logic circuit, the regenerated output is fed to the error rate counter for the BER measurement.

B. Test Results

In the following simulation test, the average signal energy per bit to noise power density ratios on the respective diversity branches are equal to each other, $\Gamma_1 = \Gamma_2 = \Gamma$. The fading rate is set equal to $f_D = 40$ Hz, corresponding to a typical mobile speed of $v = 48$ km/h $= 30$ mi/h for the 900-MHz band. The measured BER is the average of several BER measurements. Each measurement takes about 3 minutes, so that several hundred signal fades may occur in each measurement. Other parameters are

1) switching rate f_s;
2) frequency deviation Δf_d;
3) envelope correlation ρ.

Fig. 4 shows the measured average BER performance with the switching rate as a parameter for $\Delta f_d = \pm 5$ kHz and $\rho = 0$. As was expected, the test results indicate that the average BER performance is markedly improved by setting the switching rate to an optimum value. With an optimum setting, the received average signal level necessary for the average BER of 1×10^{-3} is reduced by about 10 dB relative to the signal level of a nondiversity case. This reduced quantity corresponds to the diversity gain of this system.

Fig. 5 shows the measured average BER versus switching

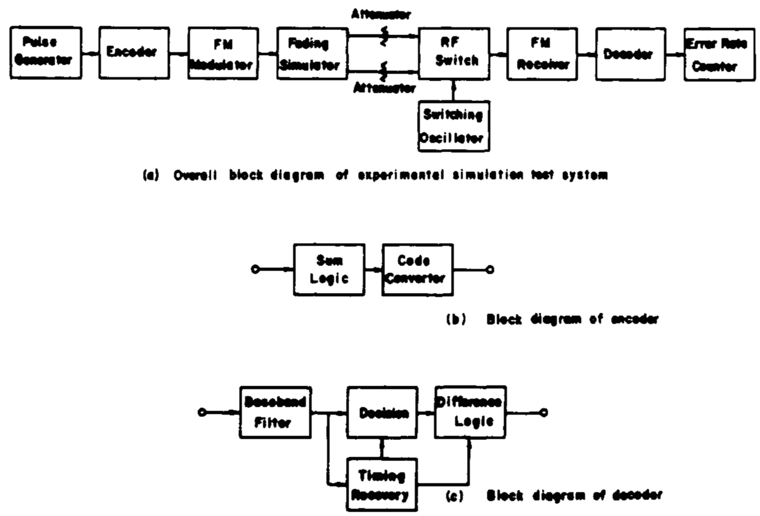


Fig. 3. Block diagram of experimental simulation test system.

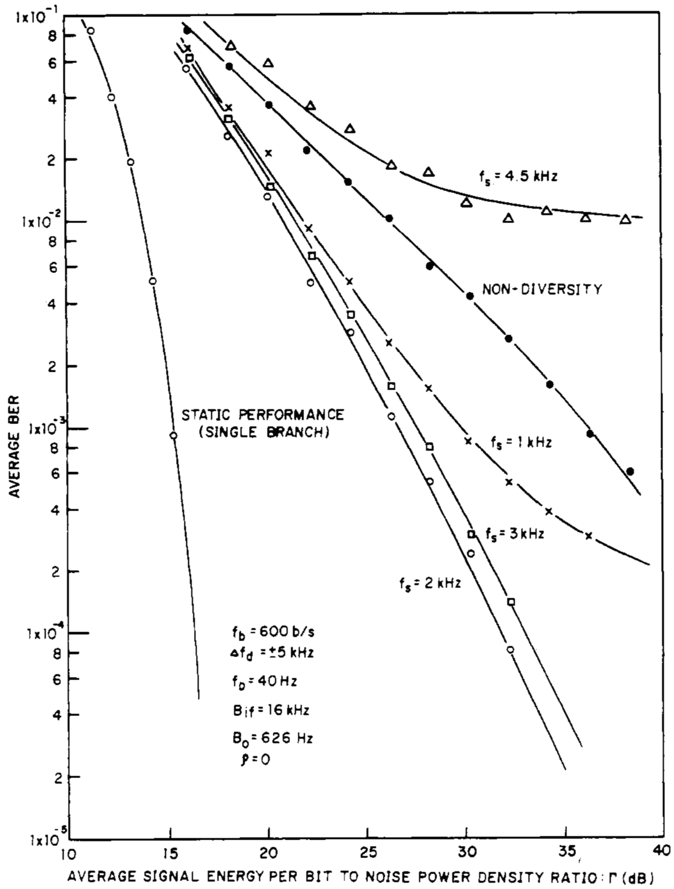


Fig. 4. Effect of switching rate on average BER performance.

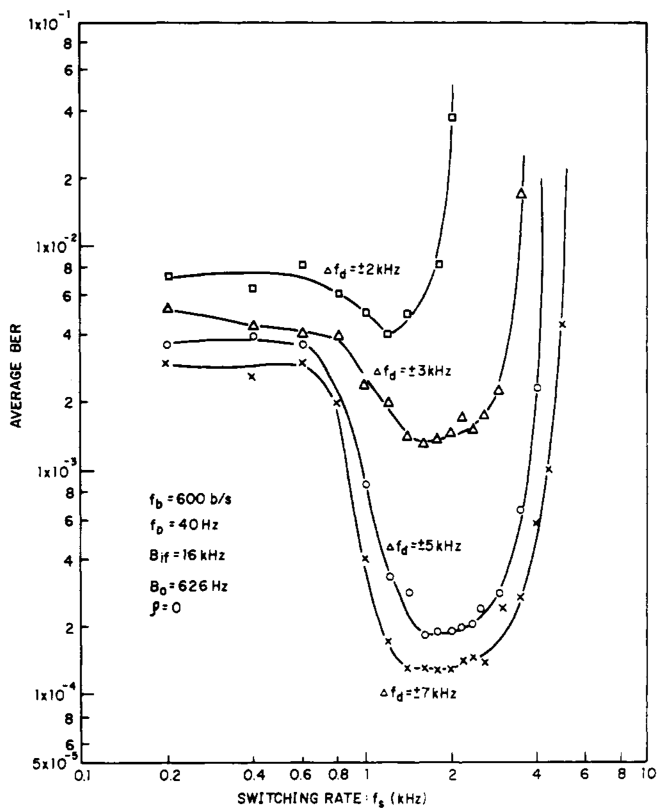


Fig. 5. Average BER versus switching rate.

rate with the frequency deviation as a parameter for $\Gamma = 30$ dB and $\rho = 0$. It is found from Fig. 5 that the optimum value of switching rate is about 2 kHz and is loosely dependent on frequency deviation.

Fig. 6 shows the measured average BER performance with the envelope correlation ρ as a parameter for $\Delta f_d = \pm 5$ kHz and $f_s = 2$ kHz. The results indicate that the improvement effect is reduced by only about 2 dB, unless the envelope correlation exceeds $\rho = 0.8$.

C. Discussion

The simulation test results surely show that the average BER performance can be improved by increasing the switching rate, but is degraded at an excessively high switching rate. Therefore, it is found that there exists an optimum value in the switching rate.

The reason why the average BER performance is degraded at an excessively high switching rate is believed to be caused by the following. When the switching rate is excessively high, the spectrum of the combined receiver input is so spread that signal distortion is caused by IF filter band restriction. As-

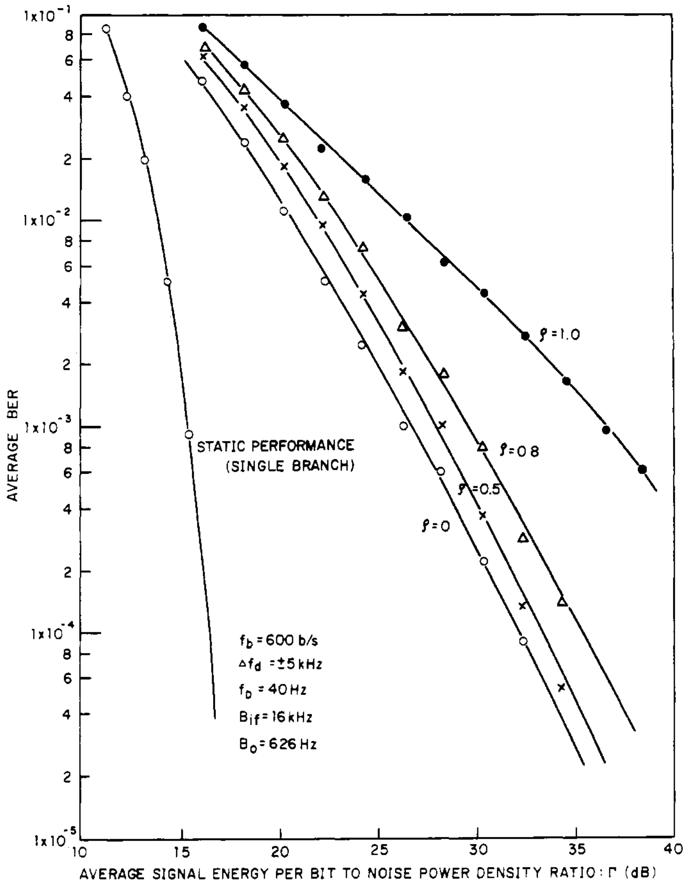


Fig. 6. Effect of correlation on average BER performance.

suming that the IF filter bandwidth is wide enough for the signal transmission, the average BER performance will not be degraded by the signal distortion. However, it will be degraded in turn by the excessively increased noise power. Therefore, there exists an optimum value in the switching rate.

The constant parameter α, included in (3), is found to be $\alpha \approx 0.2$ from experimental data on static BER performance for a bit rate of $f_b = 600$ bit/s, frequency deviation of $\Delta f_d = \pm 5$ kHz, and predetection IF filter bandwidth of $B_{if} = 16$ kHz. Since differential encoding is used in the simulation test, the measured average BER should be approximately given by $2 \times P_1$, where P_1 is given by (7) or (12). Thus the average BERs for the nondiversity case and the periodic switching diversity case with a very high switching rate are given by 5×10^{-3} and 1×10^{-4}, respectively, at an average signal energy per bit to noise power density ratio of $\Gamma = 30$ dB. As shown in Fig. 4, the simulation test results for the nondiversity case and for the diversity case with $f_s = 2$ kHz agree well with the above calculated values. The influence of correlation causes the diversity gain to be decreased by 3.5 dB for $|k|^2 = 0.8$ from (12). Considering that the envelope correlation ρ between the two fading signals is approximately given by $\rho \approx |k|^2$ [4], the simulation test results shown in Fig. 6 agree with the calculated values.

V. FIELD TEST

The field test was performed in a suburban area in order to verify the feasibility of the periodic switching diversity system in a real fading environment. In this test, a Manchester-coded FSK system with a bit rate of $f_b = 600$ bit/s and a frequency deviation of $\Delta f_d = \pm 5$ kHz was used. The switching rate was set as an optimum value of $f_s = 2$ kHz.

A. Field Test System

The block diagrams of the base and mobile station systems are shown in Figs. 7 and 8, respectively.

The base station is located on the top of Yokosuka Electrical Communication Laboratory about 160 m above the test area. The transmitter has an output power of 5 watts. The transmitter output is passed through an RF attenuator and is radiated from a base station antenna which is an 8-element Yagi antenna having a gain of 10 dB over a dipole. The RF attenuator is used to vary the received signal strength at the mobile receiver. The test pattern signal and the encoder used in the field test are identical with those used in the laboratory simulation test. The carrier frequency is 880,000 MHz.

The mobile station is in a van. Two $\lambda/4$ whip antennas are located on the ground plain above the van roof. The antenna arrangement is square to the direction of vehicle movement. Antenna spacing is variable from 3 cm to 64 cm, i.e., from 0.09 λ to 2 λ. A power divider is inserted in each diversity branch for the envelope measurement of fading signals and the BER measurement with and without diversity. An antenna switch unit is operated by an astable multivibrator with an optimum switching rate of 2 kHz. The FM receiver and the decoder are identical with those used in the laboratory simulation test. The decoder output is fed to an error detector to measure the average BER.

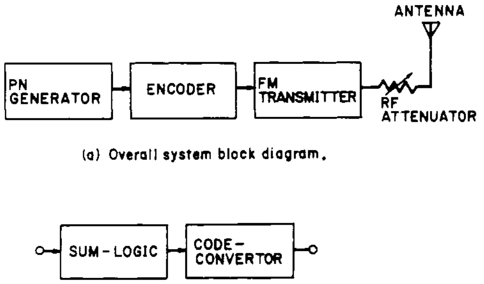
In the error detector, an exclusive-or gate compares the decoder output with a reference PN sequence generated locally by recovering the frame synchronization from the decoder output. Thus a bit error pulse occurs whenever any bit of the decoder output is different from the reference PN sequence. The outputs of the field strength measuring receivers and the error detectors are recorded in an FM tape recorder for later processing.

B. Statistical Characteristics of Field Strength

The field test area is the Kurihama area characterized by a small scale factory district, at a distance of about 3 km from the base station shown in Fig. 9. The test is made along a street, which is about 2 km around and is approximately orthogonal to a radial line of the direction between the transmitter and the receiver, at a constant moving speed of about 30 km/h.

By the measurement of the fading statistical characteristics on the received signal, it is found that the received signal envelope follows closely to the Rayleigh distribution locally and its local average follows closely to the lognormal distribution with a standard deviation of $\sigma = 3.7$ dB. The median value of the local average is 34 dBμ, i.e., the median value Γ_m of the local average Γ of the signal energy per bit to noise power density ratio is $\Gamma_m = 54.5$ dB, when the attenuation of the base station RF attenuator is 0 dB.

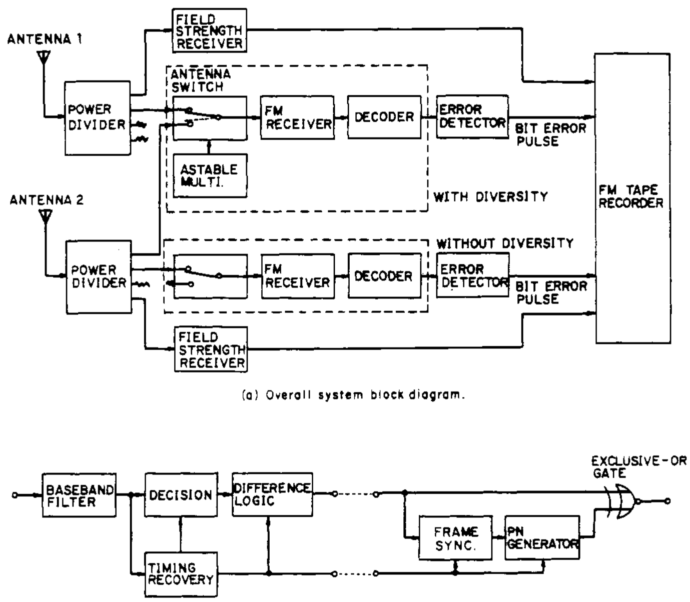
Fig. 10 shows the measured envelope correlation versus antenna spacing. The plotted value is the average of several



(a) Overall system block diagram.

(b) Encoder.

Fig. 7. Base station system.



(a) Overall system block diagram.

(b) Decoder. (c) Error detector.

Fig. 8. Mobile station system.

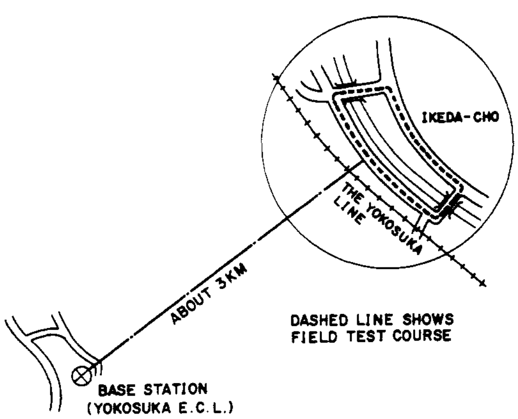


Fig. 9. Map showing field test area.

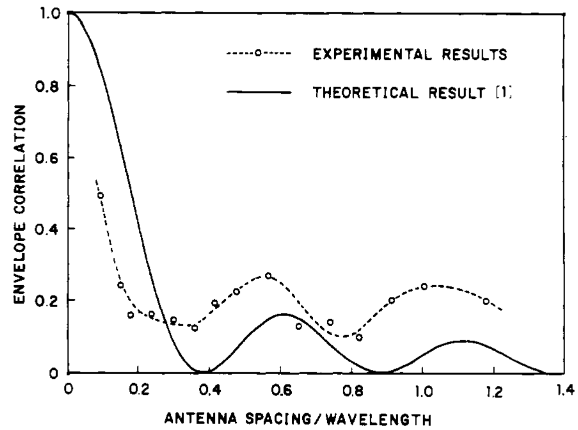


Fig. 10. Envelope correlation versus antenna spacing.

measurements. Each measurement takes 2 seconds so that each measuring distance may be about 50 wavelengths. The shape of the curves is roughly similar to the theoretically predicted one [1] without being a close fit at any point.

C. Measured Average BER Performance

The average BER is computed by counting the total number of the bit error pulses and dividing by the total number of the transmitted bits. Each measurement takes about 30 minutes, so a test signal composed of 1 080 000 bits is transmitted.

The measured average BER performances with and without diversity are shown in Fig. 11. In this case, the antenna spacing is 2 λ, so the envelope correlation is nearly zero. The test results verify that the use of the periodic switching diversity can surely reduce the received average signal level necessary for an average BER of 1×10^{-2} or 1×10^{-3} by about 5 or 10 dB, respectively, relative to that without diversity.

The influence of antenna spacing on the diversity improvement is shown in Fig. 12 for $\Gamma_m = 29.5$ dB. The diversity improvement is degraded only at an antenna spacing of 0.09 λ.

D. Discussion

From the measurement of the fading statistical characteristics, it is found that the received signal envelope follows closely to the Rayleigh distribution locally and its local average follows closely to the lognormal distribution with a standard deviation of $\sigma = 3.7$ dB. Therefore, the pdf of the local average Γ of the received signal energy per bit to noise power density ratio is given by

$$p(\Gamma)\,d\Gamma = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(10\log\Gamma - 10\log\Gamma_m)^2}{2\sigma^2}} d(10\log\Gamma) \quad (15)$$

where Γ_m is the median value of Γ. The local averages of the two fading signals received by the respective diversity antennas can be assumed to vary coincidentally since the antenna spacing is about less than a few wavelengths. Thus the average BER $P_1{}^*$ including the effect of the lognormal distribution of Γ is obtained by averaging the local average BER P_1 in the Rayleigh fading with constant average power, which is given in (7) or (12), over $p(\Gamma)$. The average BER $P_1{}^*$ with and without diver-

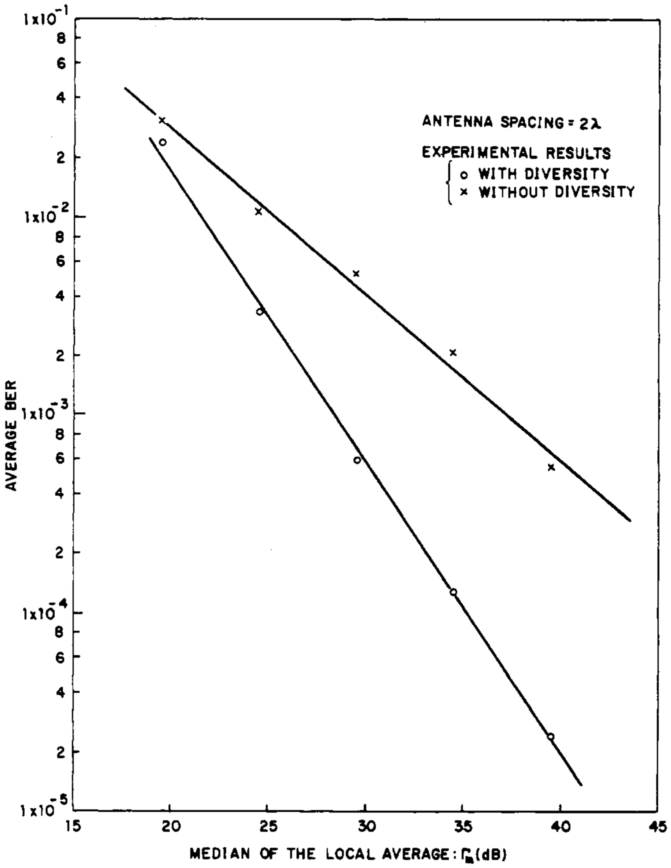


Fig. 11. Average BER versus median of the local average.

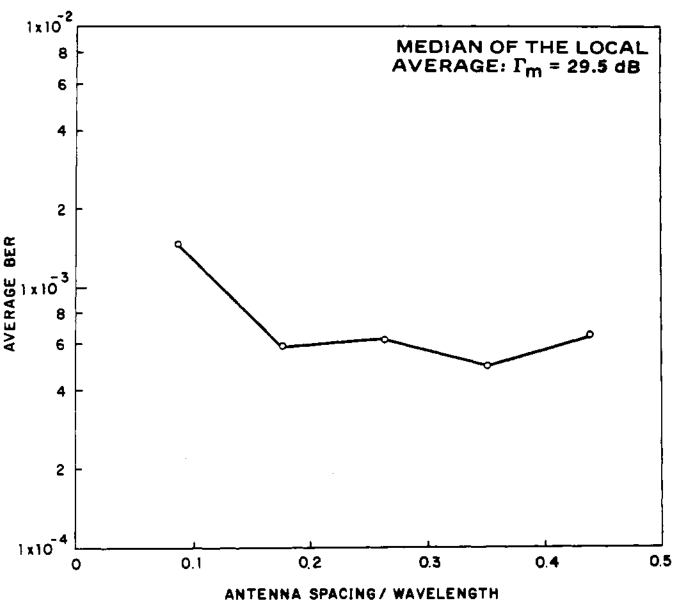


Fig. 12. Average BER versus antenna spacing.

sity are given by, respectively,

$$P_1{}^* = \int_0^\infty P_1(\Gamma)p(\Gamma)\,d\Gamma$$

$$\approx \frac{2}{\alpha^2(1-|k|^2)} \int_0^\infty \Gamma^{-2} p(\Gamma)\,d\Gamma$$

$$= \frac{2}{\alpha^2(1-|k|^2)\Gamma_m{}^2} e^{\left\{\frac{\sqrt{2}\ln 10}{10}\sigma\right\}^2} \quad (16)$$

$$P_1{}^* \approx \frac{1}{2\alpha\Gamma} e^{\frac{1}{4}\left\{\frac{\sqrt{2}\ln 10}{10}\sigma\right\}^2} \quad (17)$$

Since the differential encoding is used, the measured average BER should be approximately equal to $2 \times P_1{}^*$. The constant parameter α is about 0.2 as shown in Section IV. Thus the average BER with and without diversity are about 4.3×10^{-4} and 7.1×10^{-3}, respectively, when $\Gamma_m = 30$ dB. As shown in Fig. 11, the field test results agree well with the above calculated values.

The measured envelope correlation between two fading signals is about 0.5 for an antenna spacing of 0.09 λ as shown in Fig. 10. Since the envelope correlation is approximately equal to $|k|^2$ [4], an antenna spacing of 0.09 λ causes the value of the average BER to be increased by two times as much from (12). The field test results shown in Fig. 12 agree with the above result.

VI. CONCLUSION

This paper describes a simple switching diversity technique to receive two RF signals periodically by switching two antenna branches at a rate moderately higher than the bit rate.

After the background for the concept was described, the cause of diversity effect was explained as being due to transforming the probability density function of signal energy per bit to noise power density ratio to a sharper distribution with smaller variance. Then, the feasibility of this periodic switching diversity technique was verified by the laboratory simulation and field tests.

Although a similar diversity effect can also be obtained for co-channel interference performance, adjacent-channel interference performance may not be improved since periodic switching would tend to cause spectrum foldover into the desired channel band. This is a potential problem which is an area for further study.

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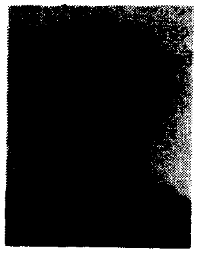

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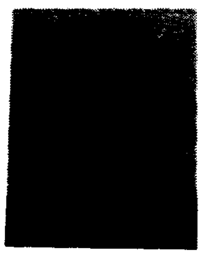

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